# VISION 21
# HYBRID CONCEPTS

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# VISION 21 PROGRAM OBJECTIVES

- **PRODUCE ELECTRICITY AND TRANSPORTATION FUELS AT COMPETITIVE COSTS**
- **MINIMIZE ENVIRONMENTAL IMPACTS ASSOCIATED WITH FOSSIL FUEL USEAGE**
- **ATTAIN HIGH EFFICIENCY**
  - **NATURAL GAS - 75% (LHV)**
  - **COAL - 60% (HHV)**
    **(W/O CO2 CAPTURE/SEQUESTRATION & CO-PRODUCTS)**

# PROGRAM OBJECTIVE

- **IDENTIFY NATURAL GAS AND COAL BASED CYCLE CONFIGURATIONS THAT MEET V21 GOALS**

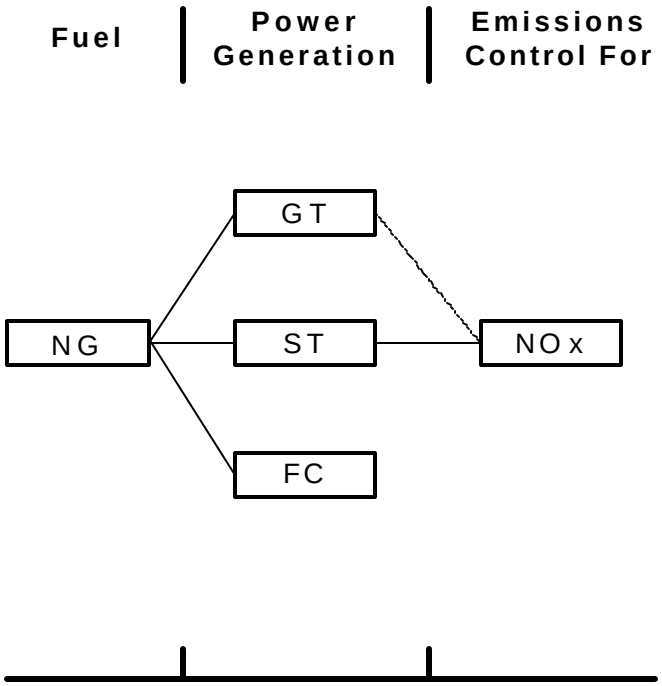
# PROGRAM APPROACH

- **SUB-SYSTEM SELECTION – SELECT FUEL PROCESSING, POWER GENERATION, AND EMISSION CONTROL TECHNOLOGY SCENARIOS WITH POTENTIAL TO ACHIEVE V21 GOALS**

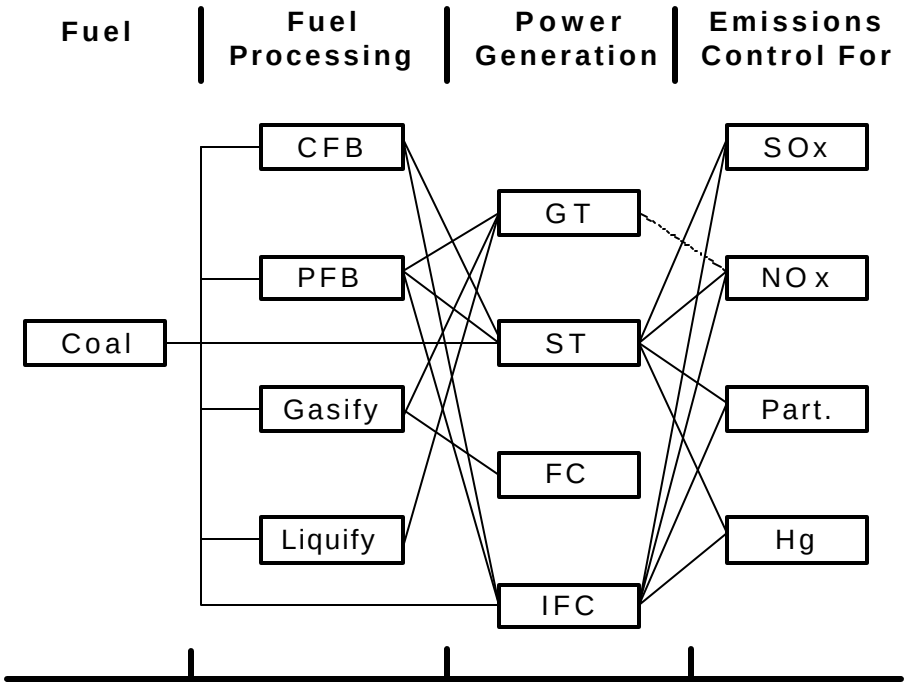
- **SCREENING ANALYSIS – ANALYZE/OPTIMIZE SELECTED TECHNOLOGY SCENARIOS TO SELECT CYCLE CONFIGURATIONS**
  - **START WITH BASIC DESIGN WITH RELATIVELY NEAR TERM TECHNOLOGY**
  - **IF V21 TARGETS NOT REALIZED, INCORPORATE MORE ADVANCED DESIGNS**

- **DETAILED ANALYSIS – ANALYZE SELECTED PROMISING CYCLES TO DEVELOP DETAILED PERFORMANCE AND COST ESTIMATES**

# SUB-SYSTEM SELECTION




(a) Natural Gas Fueled



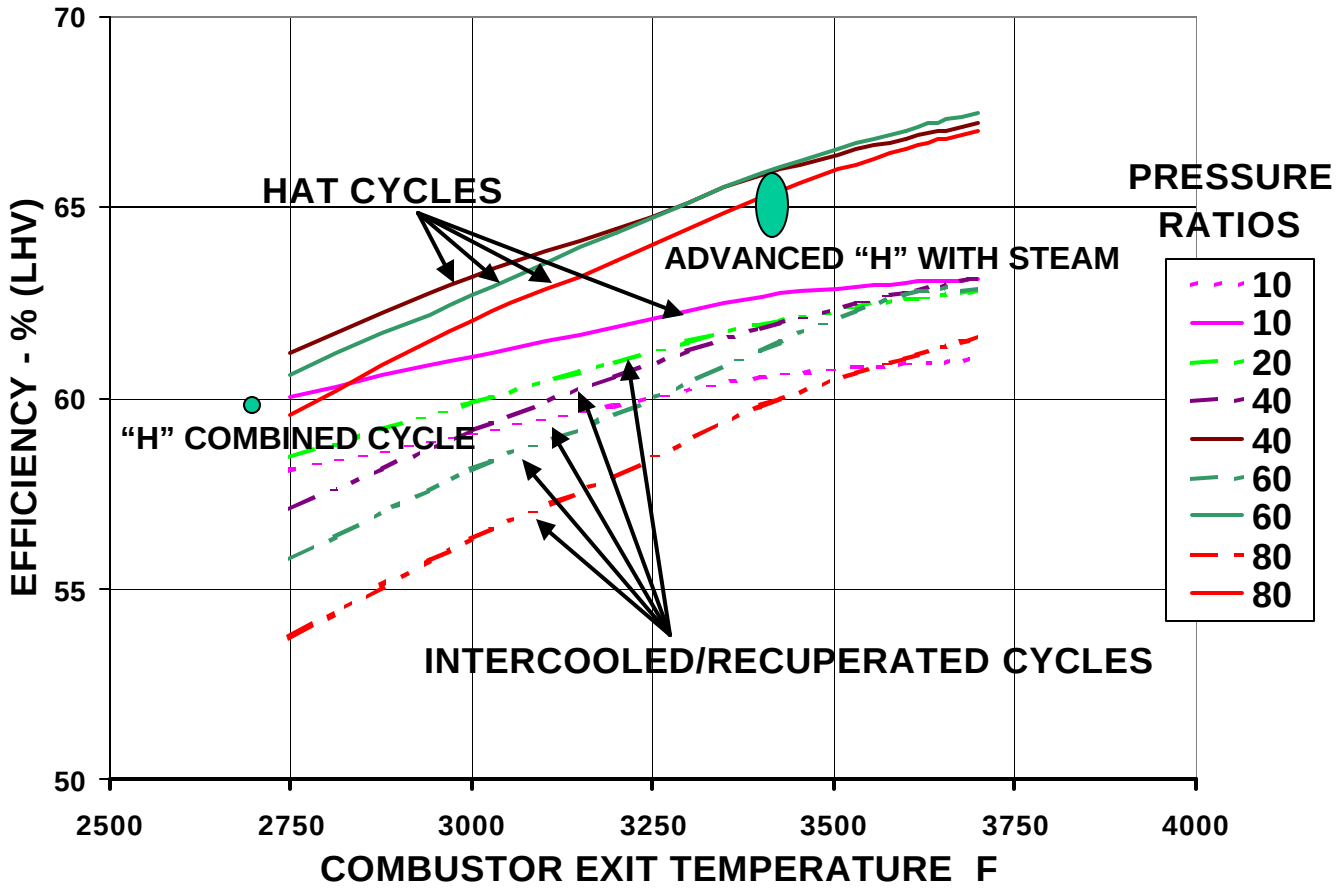

(b) Coal Fueled

NG-Natural Gas
CFB-Circulating Fluided
FC-Fuel Cell
GT-Gas Turbine

PFB-Pressurized Fluid Bed
IFC-Indirectly Fired Cycle
ST-Steam Turbine

# GAS TURBINE W/O FUEL CELL NOT SUFFICIENT

## GT-BASED CYCLE EFFICIENCIES



# SUB-SYSTEM SELECTION

- **GAS TURBINES + FUEL CELLS ARE REQUIRED TO ATTAIN V21 EFFICIENCY GOALS**

- **COAL MUST BE CONVERTED TO CLEAN GAS TO UTILIZE GAS TURBINES/FUEL CELLS Þ GASIFICATION**

# DESIGN BASIS

- **ISO CONDITIONS**
- **NOMINAL PLANT OUTPUT:** **300 MW**
- **FUELS:** **Natural gas**

  **Coal (Illinois # 6)**
- **GT FIRING TEMP:** **≤ 3100 F**
- **GT COMRESSOR EFFICIENCY:** **90%+ (Isentropic)**
- **GT EXPANDER EFFICIENCY:** **93%+ (Isentropic)**
- **GT COOLING TECHNOLOGY:** **Ceramics/TBC/Air/Humid Air**

# SCREENING ANALYSIS
# NATURAL GAS CASES

## THERMAL EFFICIENCY

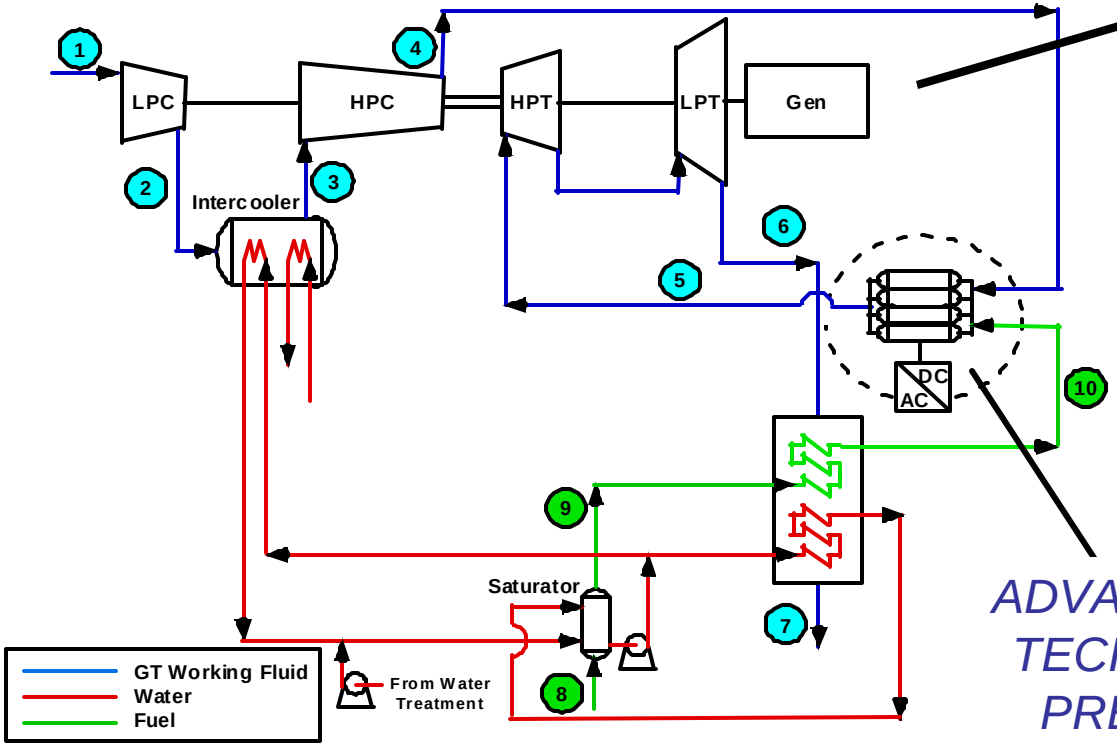
- **HIGH PRESSURE SOFC / IC GT HYBRID**
- **HIGH PRESSURE SOFC / HAT HYBRID**
- **ATMOSPHERIC PRESSURE MCFC / CHEMICALLY RECUPERATED GT (WITH HITAF) HYBRID**

## $CO_2$ RECOVERY

- **$O_2$ BREATHING HIGH PRESSURE SOFC / HAT WITH TEMP MODERATED BY $CO_2$ RECYCLE**
- **ADVANCED RANKINE CYCLE (GT) WITH CES COMBUSTOR & HIGH TEMP $H_2$ SEPARATING MEMBRANE**

# High Pressure IC GT / SOFC

$\eta_{LHV} > 75\%$, $\pi_{OPT} \cong 50$



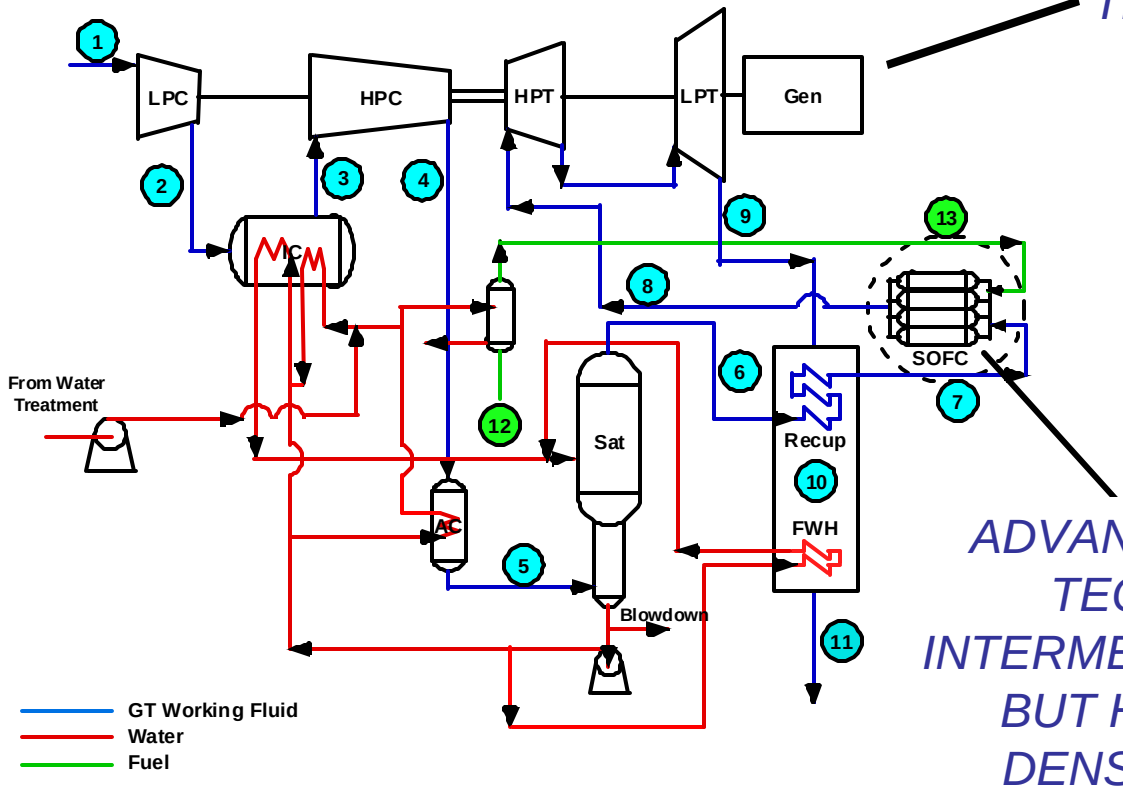

*ADVANCED GAS TURBINE TECHNOLOGY – INTERCOOLED GT REQUIRED*

*ADVANCED FUEL CELL TECHNOLOGY - HIGH PRESSURE & HIGH CURRENT DENSITY REQUIRED*

# HAT / SOFC

$\eta_{LHV} > 75\%, \pi_{OPT} \cong 20$

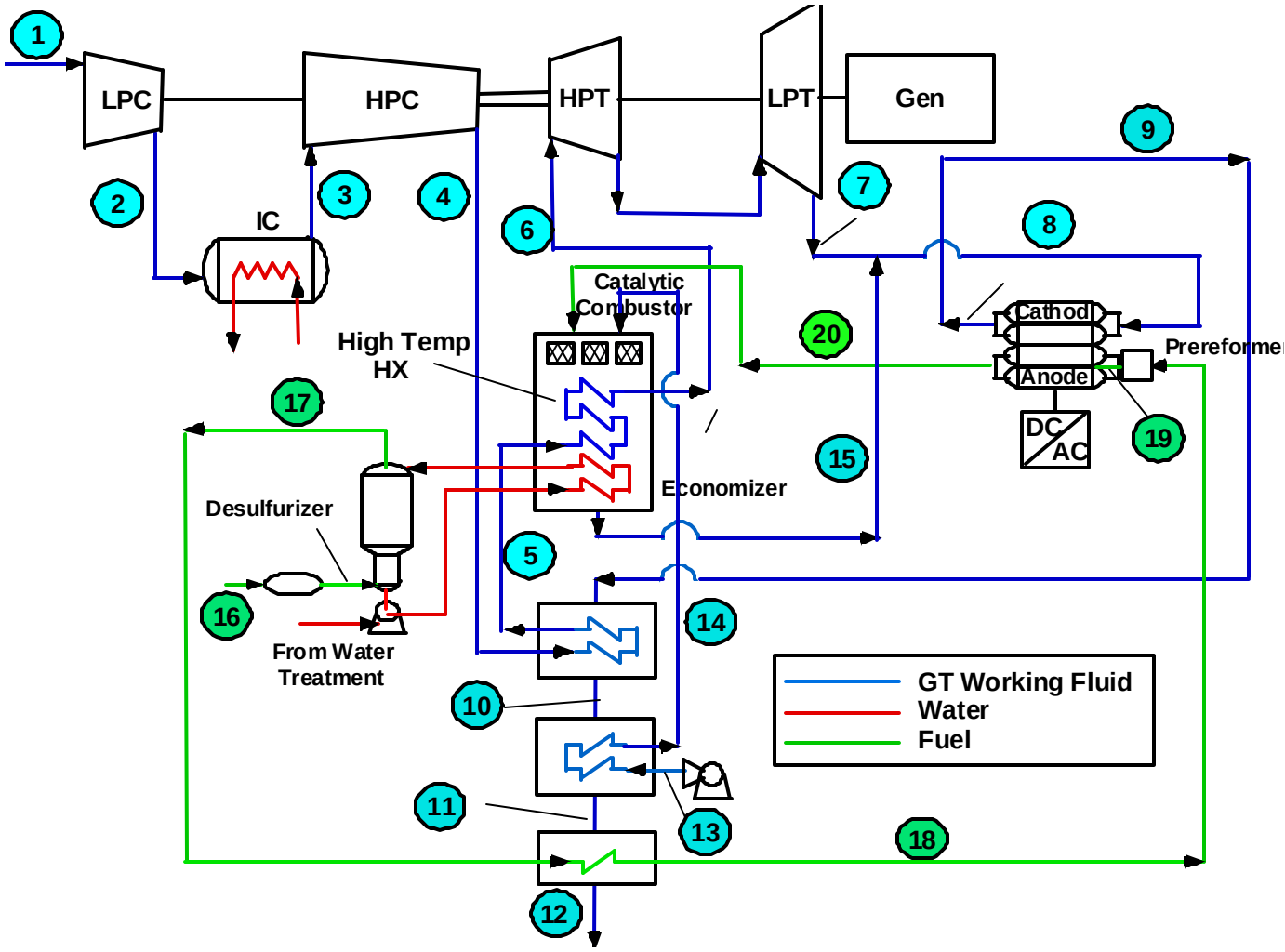
*ADVANCED GAS TURBINE TECHNOLOGY – HAT REQUIRED*




*ADVANCED FUEL CELL TECHNOLOGY – INTERMEDIATE PRESSURE BUT HIGH CURRENT DENSITY REQUIRED*

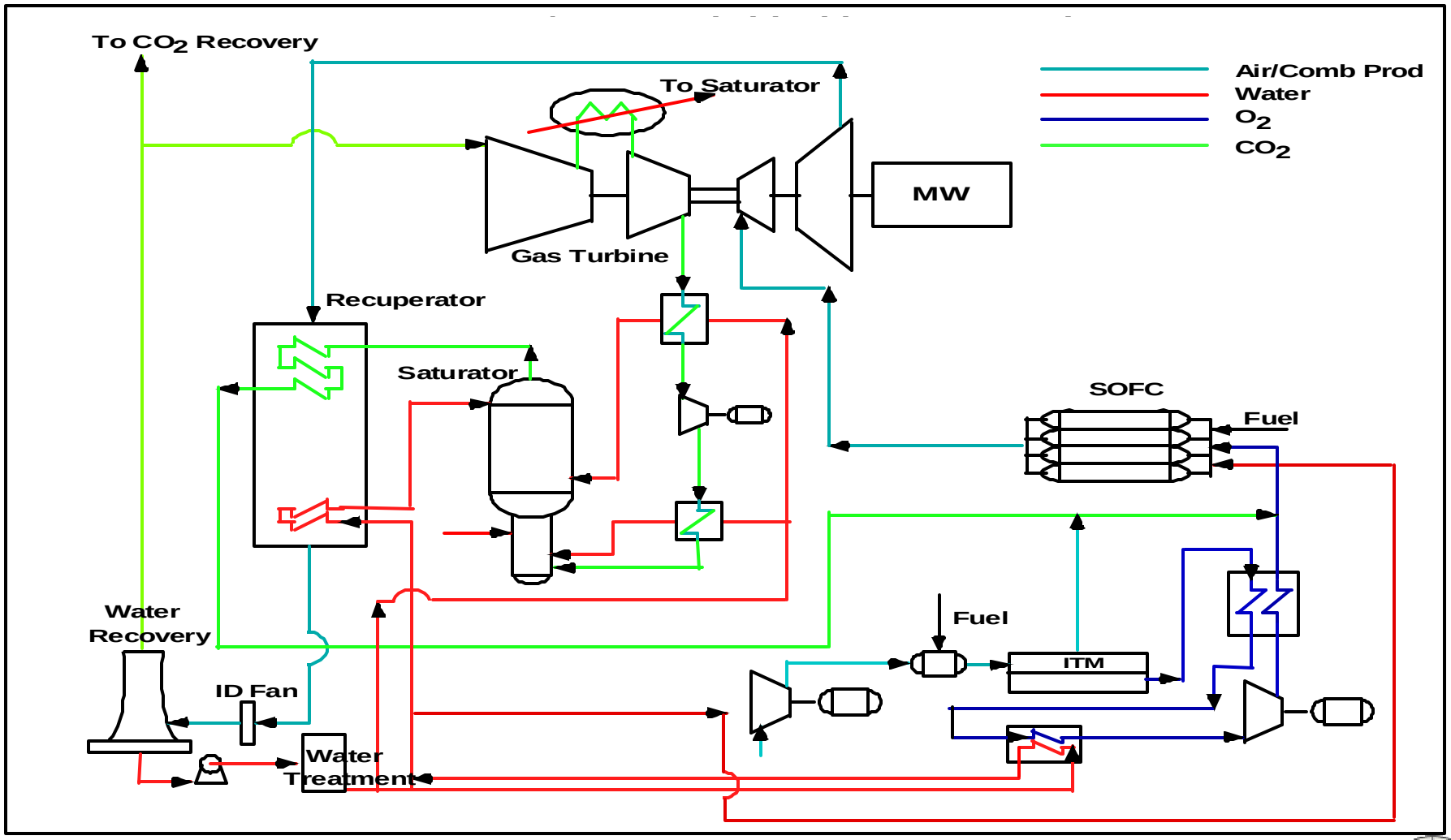
# Chemically Recuperated GT / Bottoming MCFC

$\eta_{LHV} \cong 70\%$, $\pi_{OPT} \cong 25$



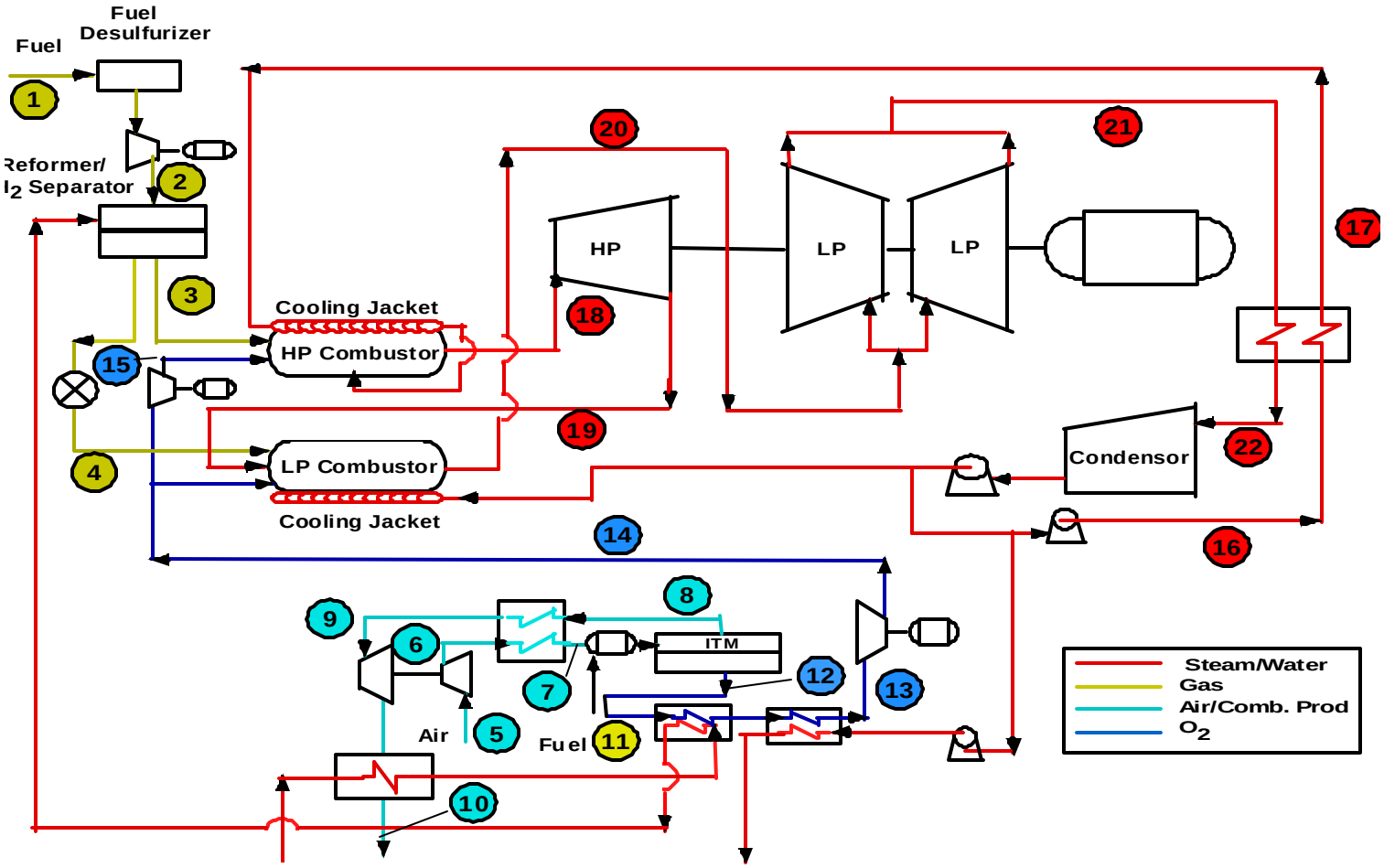
# HAT / $O_2$ Blown SOFC with $CO_2$ Recycle

$\eta_{LHV} > 60\%$, $\pi_{OPT} \cong 20$



# Advanced Rankine (GT) / CES Combustor / HT $H_2$ Separating Membrane

$\eta_{LHV} \cong 52\%$, $\pi \cong 3200$



# PERFORMANCE COMPARISONS

## Natural Gas Based Cycles

| | HP SOFC + IC GT HYBRID | HP SOFC + HAT HYBRID | ATM P MCFC + IC GT HYBRID | $O_2$ BREATHING HP SOFC + HAT HYBRID | ADV RANKINE ($H_2/O_2$ COMBUSTION) |
|---|---|---|---|---|---|
| % OF TOTAL POWER BY FUEL CELL | 72 | 68 | 74 | 68 | - |
| % OF TOTAL POWER BY GAS TURBINE | 28 | 32 | 26 | 32 | 100 |
| THERMAL EFFICIENCY, % LHV | >75 | >75 | 70 | >60 | 52 |
| SPECIFIC POWER, KW/LB/S | 985 | 1000 | 830 | 800 | - |

# SCREENING ANALYSIS
# COAL BASED CASES

## THERMAL EFFICIENCY

- SHELL GASIF / HT CLEANUP - SOFC HYBRID
- TEXACO GASIF – SOFC / HAT HYBRID
- F-W PARTIAL GASIF - SOFC / HITAF GT HYBRID

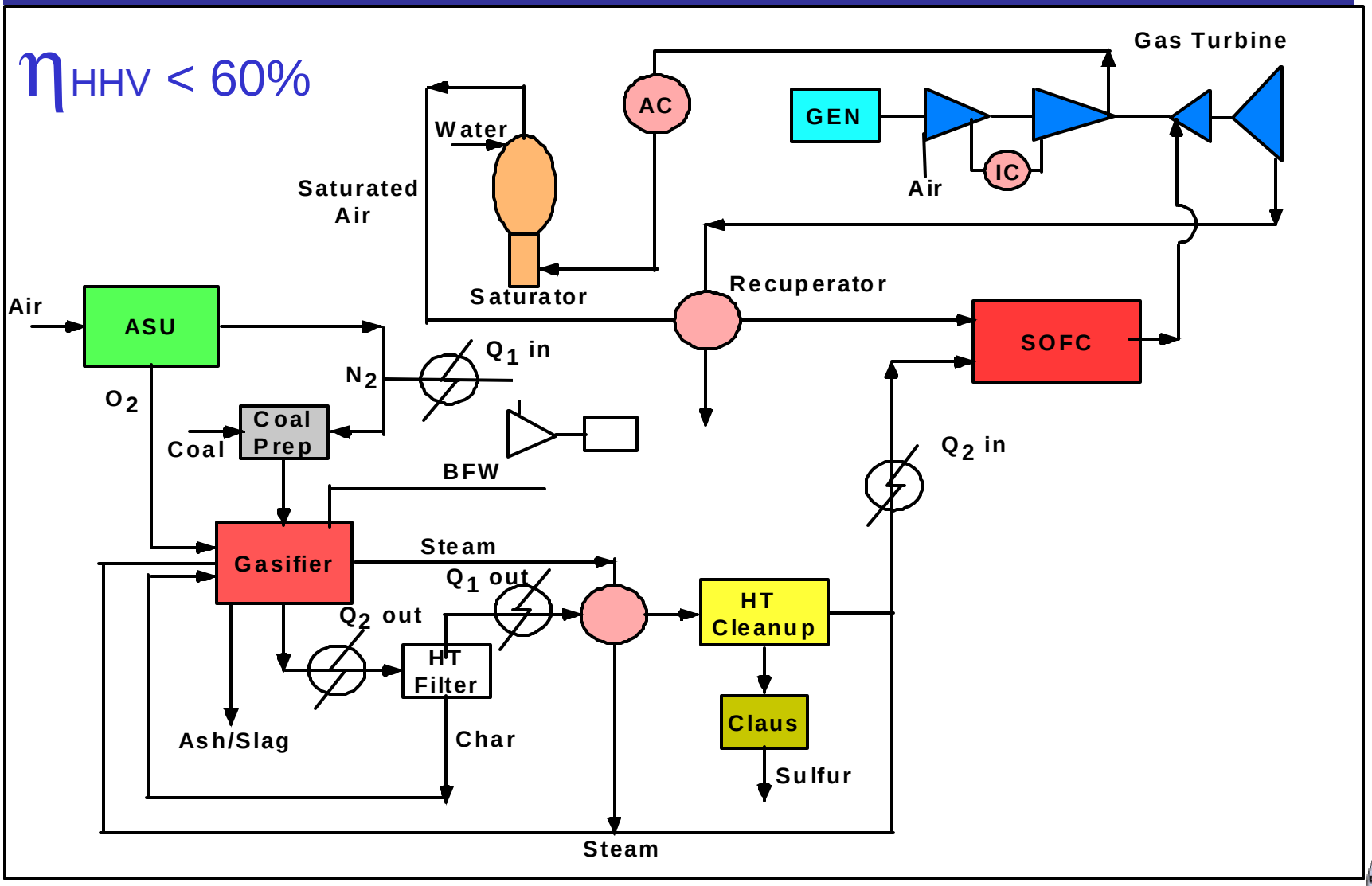
## $CO_2$ RECOVERY

- SHELL GASIF / HT CLEANUP - $O_2$ BREATHING H P SOFC / HAT WITH TEMP MODERATED BY $CO_2$ RECYCLE
- SHELL GASIF / HT CLEANUP / SHIFT / HT $H_2$ MEMBRANE SEPARATION - ADVANCED RANKINE CYCLE (GT) - CES COMBUSTOR

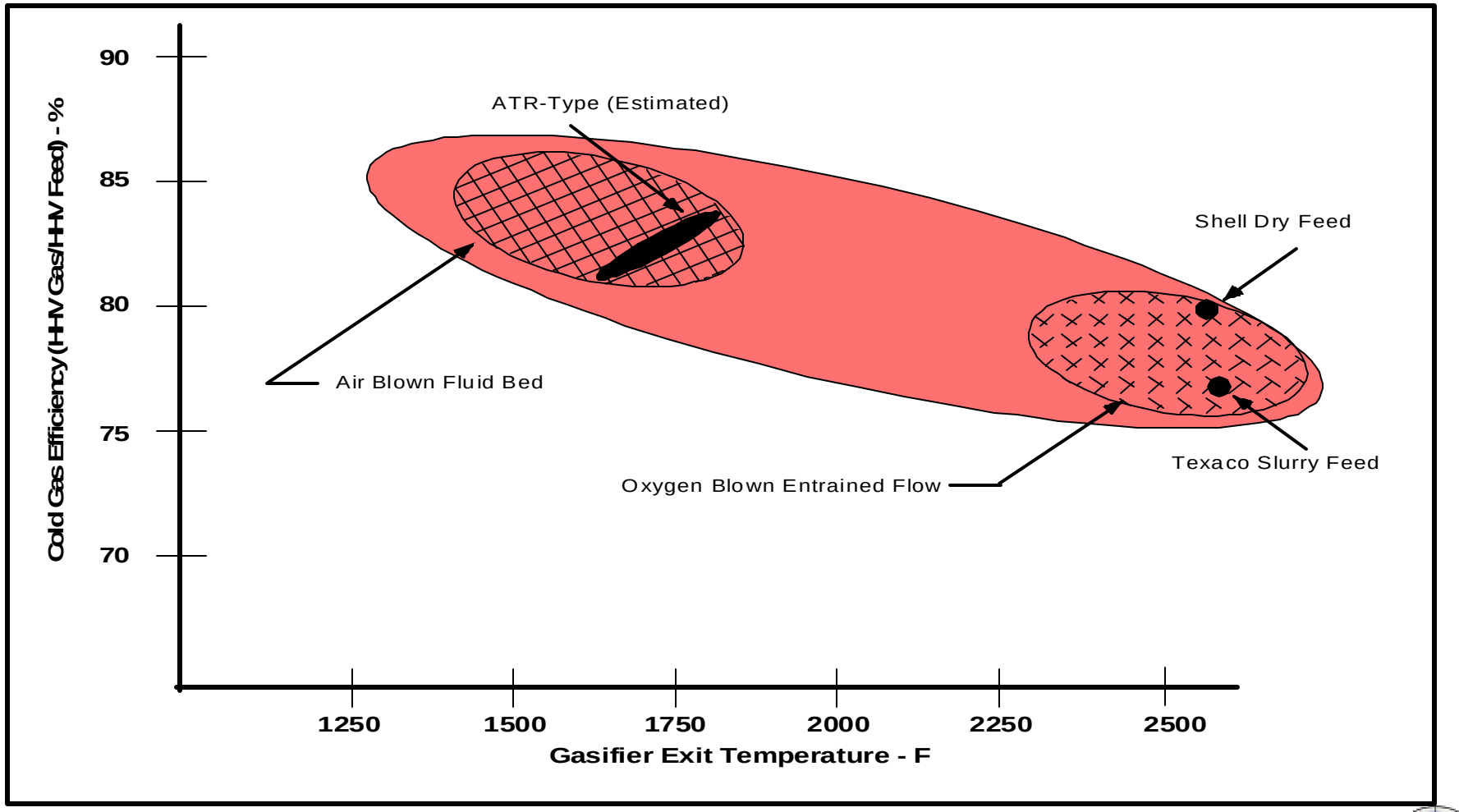
## COPRODUCTION

- TEXACO IGHAT WITH F-T LIQUIDS

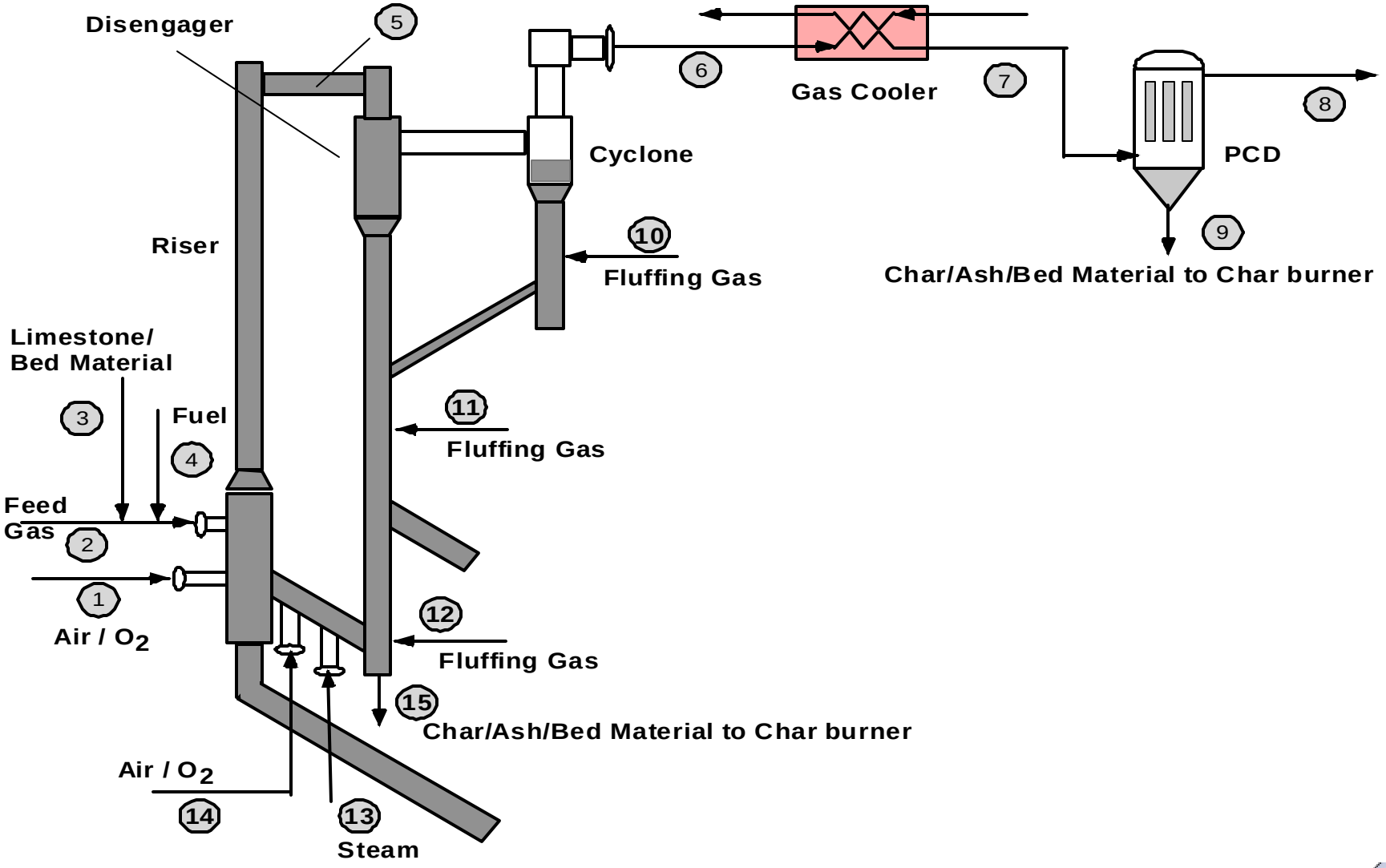
# HT GASIFICATION WITH HT GAS COOLING HAT/SOFC



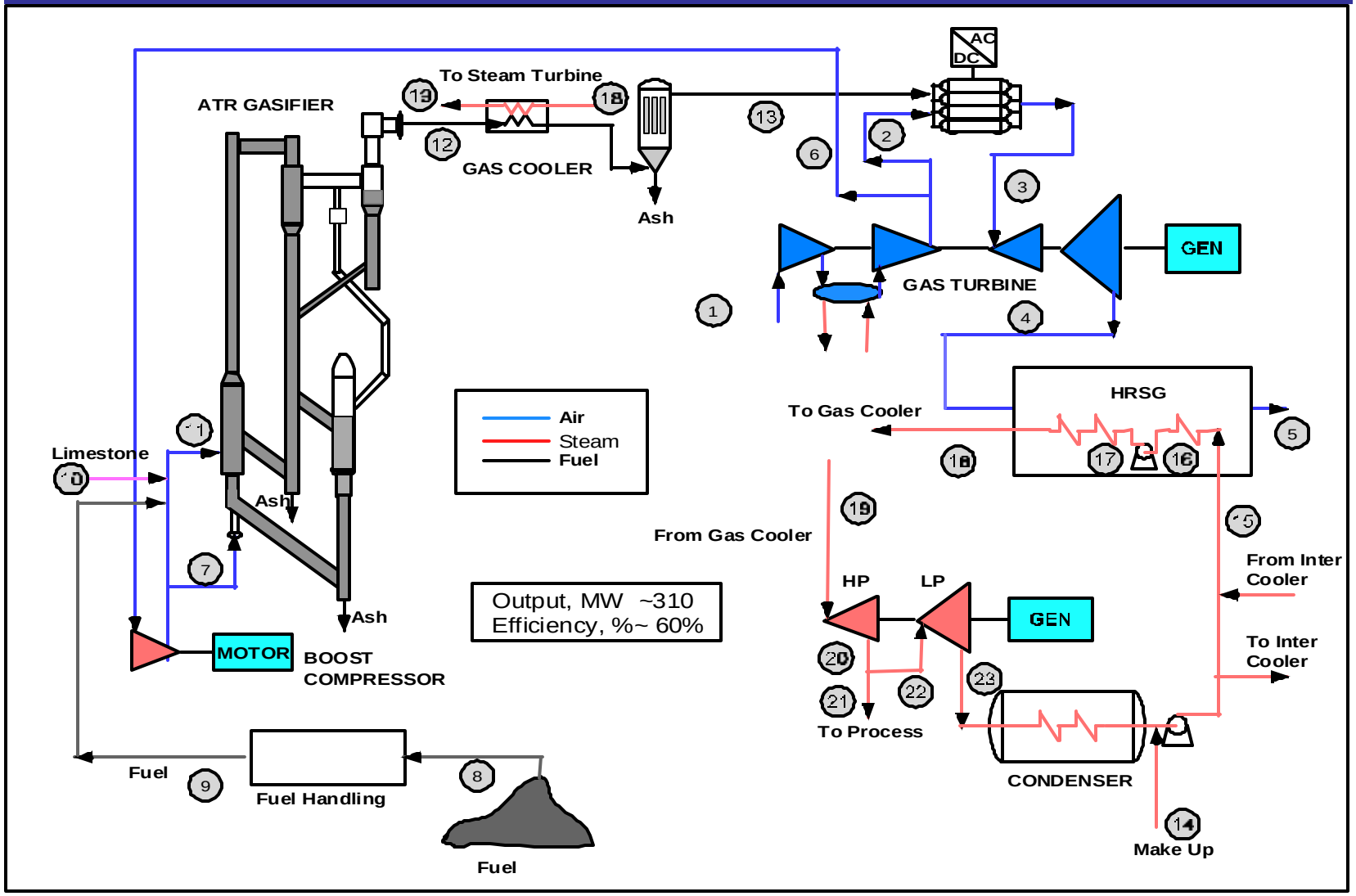
# GASIFIER OPERATING TEMP VERSUS COLD GAS h



# MODERATE TEMP GASIFICATION ADVANCED TRANSPORT REACTOR



# LT GASIFICATION WITH HT GAS COOLING SOFC HYBRID



# SUMMARY

## NATURAL GAS

- PRESSURIZED SOFC HYBRID CONFIGURATIONS IDENTIFIED WITH > 75% EFFICIENCY (85% FUEL UTILIZATION)
- ATMOSPHERIC PRESSURE MCFC CONFIGURATIONS IDENTIFIED > 70% EFFICIENCY (85% FUEL UTILIZATION, EFFICIENCY >75% AT 90% FUEL UTILIZATION)
- $O_2$ BREATHING SOFC HYBRID CONFIGURATION WITH $CO_2$ RECOVERY IDENTIFIED WITH 60% EFFICIENCY

## COAL

- CONVENTIONAL HT GASIFICATION BASED HYBRID EVEN WITH HT GAS COOLING DIFFICULT TO MEET V21 EFFICIENCY GOAL
- NEED LOWER TEMP GASIFICATION

# PROJECT STATUS

- **COMPLETED SCREENING ANALYSES OF NATURAL GAS BASED CYCLES, INCLUDING OPTIMIZATION**
- **SCREENING ANALYSES OF COAL BASED SYSTEMS INITIATED, TO BE COMPLETED BY THE END OF 2002**
- **DETAILED ANALYSIS TO BE COMPLETED IN 2003 INCLUDING**
  - **PART-LOAD PERFORMANCE**
  - **AMBIENT TEMP SENSITIVITIES**
  - **COST**